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# *PHOTOGRAPHY OF THE SOLAR PROMINENCES.*

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THE most remarkable developments of astronomy in recent years have been effected by photographic means. Thousands of star images secured upon a single plate; faint and far-reaching nebulæ clearly and permanently recorded; star spectra showing hundreds of lines; sun-spots in the greatest perfection of detail; — these are a few evidences of the great value of the sensitive plate to the astronomer. And the great success of the many investigators in this new field of research has so multiplied the applications of photography that there are few instances in which it has not already surpassed the most searching eye.

As photography has thus been employed in almost every department of astronomical research, it is rather to be wondered at that the solar prominences have as yet escaped its attacks. A simple and reliable method of photographing the prominences would not only do away with the tedious and inaccurate task of drawing, but might possibly discover new phenomena of value in clearing up the perplexing questions of the solar theory. A series of photographs of the same prominence, taken at exactly equal intervals of time, would be of much greater value than a similar series of drawings. And if the method could be made to serve in a daily registry of solar phenomena, its value would be beyond question. It might here be contended that the photograph would integrate all changes taking place during the exposure; but if this time could be made very short, the difficulty would disappear.

There are yet other opportunities for photography. In eye observations we are limited to the visible portion of the spectrum, while photography would lay open the infra-red and ultra-violet, where the prominences are known to have many lines. It would permanently register all the phenomena of the distortion and displacement of lines in the spectrum, and render their measurement a leisurely and exact process with the dividing engine; and it might ultimately lead to a more certain knowledge than we now possess of the true form of a prominence. In an observation or photograph through, for instance, the C line, what is shown is that portion of the prominence which is composed of incandescent hydrogen. A photograph taken through an iron line, if one were visible at the time, would show the region occupied by iron vapor. In the same way, the parts played by calcium, sodium, magnesium, and other elements, might be shown; and a composite photograph from such a series of negatives would for the first time (outside of an eclipse) show the true form of the prominence, and the arrangement of its metallic strata. It is now known from comparisons of observations made just before and after eclipses with those during totality, that the C line gives the true form very nearly, if not exactly; but there is still room for much work in this direction, and in many others. For instance, Is the form seen through $D_3$ exactly the same as that seen through C? If not, are they more alike at some times than at others? Answers to questions such as these might render less mysterious the true nature of "helium," and define its relation to hydrogen. Tacchini's eye observations of prominence forms through several of the brighter lines show how advantageously photography might be employed.

Several attempts have been made at various times to photograph the prominences, but I will omit a discussion of the methods in this paper, merely remarking that no results of value have been obtained. Professor Young succeeded in obtaining the outlines of two prominences through an open slit; but the conditions under which they were made were not favorable, and no details were secured. Lohse's apparatus is too crude mechanically to be of practical service.

I believe that the following considerations will ultimately lead to a successful solution of the problem.

First. The desired dispersion may be obtained by the use of a large diffraction grating, mounted with a pair of telescopes of large aperture. The grating should be bright in the second or third order if a ruling with about fourteen thousand lines to the inch is used. Suitable absorbing media.will be required before the slit to cut out the overlapping spectra. The spectroscope should be mounted upon an equatorial refracting telescope.

Secondly. It is a well known fact, that the solar line C is the best line for prominence observation because of the brilliant and well defined images seen through it. Therefore this line, in spite of its position at the red end of the spectrum, should be used in preference to any other for prominence photography. Ordinary dry plates are more sensitive to the region of the spectrum near F and $H\gamma$, but the nebulous character of these lines makes it more desirable to use C, though for sharpness even this line is not all that could be desired. Hence special plates, sensitive to red light, are required. $D_3$ is a very sharp line, and as it is always visible as far above the limb as C, it is also recommended for photographic work, though the continuous spectrum at this point may prove troublesome. This line would of course require the use of plates sensitive to the yellow rays.

Thirdly. For photographing the prominences two new methods are offered. In general, they are as follows.

Method A. Change the rate of the driving clock of the telescope, so as to make the sun's limb move slowly across the slit of the spectroscope. Move the photographic plate in the plane of dispersion, and at right angles to the axis of the observing telescope; its velocity will depend upon the form of spectroscope employed. In this manner a series of images of the slit would be formed side by side, and merging into each other, thus building up an image of the prominence.

This method would allow the use of a narrow slit, thus greatly reducing the atmospheric light and increasing the sharpness of the photograph. A second slit should be placed immediately in front of the plate, and so nearly closed as to allow the line in use to pass. This would cut out the continuous spectrum on either side, and leave the photograph of the prominence in strong contrast on a clear background. In practice it is impossible to fully realize this, but still the second slit can be closed to such an extent as greatly to reduce the superfluous light. The use of a second slit is not in itself new, as it was employed by Huggins and others as an aid in eye observation, and by Lohse in his "rotating spectroscope." It is easy to see that a radial slit would probably prove most useful for this work. But there are at a given time only two positions on the sun's limb at which the slit may be radial when the direction of the sun's motion is at right angles to it. Thus, if the prominence did not happen to be at either of these points, it could not be photographed to the very best advantage. But it is not absolutely essential that the motion should be at right angles to the slit, and in this case a prominence could be photographed at any point on the limb. The chromosphere and all the prominences visible at one time could be taken upon one plate by reducing the diameter of the solar image until it becomes less than the length of the slit; the sun being then allowed to move across centrally.

Method B. This method is similar in principle to the above, but the result is effected in a different way, making a radial slit applicable to any portion of the limb. Provide the slit with a uniform motion across the axis of the collimator. Before the photographic plate arrange a second slit, and cause this to move with the first slit by means of a screw; both screws being provided with grooved heads for a cord, and driven by a single clock. In this case the plate and sun's image must be stationary. The slit then moves across the prominence, and the second slit prevents the plate from fogging.

These are methods devised by me a year ago. Some recent changes and improvements will be mentioned after describing the work already accomplished.

Through the kindness of Prof. E. C. Pickering the fifteen-inch equatorial of the Harvard Observatory was placed at my disposal in November, 1889. But as Mr. George Clark considered the weight of my large spectroscope too great to be safely carried by the wooden tube of the equatorial, it was finally decided to adapt the spectroscope to the twelve-inch horizontal telescope, which Professor Pickering very kindly gave up entirely to my use, although it was at that time employed for photometric work. This instrument consists of a telescope tube with twelve-inch objective supported horizontally. Light from any body not too far from the meridian is reflected into the tube by an eighteen-inch silvered glass mirror. This rests upon an iron plate in a cradle, which can be rotated by a friction roller attached to a long rod leading into the eye end of the telescope, thus giving the motion in altitude. The axis of the telescope is at right angles to the meridian, and a screw at the back of the mirror gives the motion in azimuth. This screw is driven by an endless cord in connection with a clock placed convenient to the hands of the observer, so that its rate can be easily regulated by screwing up or down the friction disk of a centrifugal governor. As the mounting is alt-azimuth, the image of the sun cannot be kept stationary by the clock, and Method B could not therefore be tried with this telescope.

The spectroscope was constructed for me by Mr. J. A. Brashear, and has proved itself in every respect a most excellent instrument. The slit is made of glass-hardened steel, gilded to prevent rust, and opens equally in both directions from the centre, the width being read off from a graduated head. The whole slit-plate is provided with a screw motion across the end of the collimator, — a very convenient motion in prominence or spot observation, and also necessary in Method B. A simple device allows three spectra to be taken edge to edge on the same plate. The lenses of the collimator and observing telescope are exactly alike, about $3\frac{1}{4}$ inches aperture and $42\frac{1}{2}$ inches focus, and are made of Jena glass. The whole collimator tube can be moved by a screw through collars in the frame, and thus the slit can be easily brought to the focus of the large telescope without moving the whole instrument. The grating is one of the excellent rulings of Professor

Rowland, and is remarkably bright in one of the second spectra. It is ruled with 14,438 lines to the inch on a highly polished surface of speculum metal, and contains altogether more than 48,000 lines. It is mounted in a holder with adjusting screws at the top and side, and stray light is excluded by a cylindrical brass cover, provided with close fitting openings for the two telescopes. The circular plate upon which the grating-holder stands is divided on its edge to degrees for convenience in setting, and a rod connected with a tangent screw carries the slow motion to the eye end of the spectroscope; a quick motion is also supplied. Eye-pieces of various powers are used for observation, either with an adapter at the end of the tube, or at the side with a total reflecting prism when the sliding plate-holder is in position. In the apparatus as first used, a small plate-holder was held by a spring clip in a light frame of brass tubing arranged to slide with very little friction between V-shaped guides. After many experiments the steadiest motion that could be obtained was derived by a fine wire from the clock of the horizontal telescope. But this was at best unsatisfactory, and several improvements have recently been devised to overcome the difficulty. An adjustable slit, directly in front of the plate and very near its surface, was used as described in Method A. The whole spectroscope is supported in a strongly braced frame of steel tubing, and by means of a gear and either one of two pinions it is easily rotated about the axis of the collimator. This allows the slit to be made tangent or radial at any point on the sun's limb.

At first thought, it would seem that the horizontal telescope offers many advantages for spectroscopic work. As the tube is always retained in a fixed position, and rests on solid brick piers, apparatus of great weight may be attached to the eye end without causing sensible flexure of the tube. The spectroscope is thus always conveniently placed for observation, and work may be carried on with comfort even in the coldest weather, as the observer sits in a small house, which may be warmed with a stove if so desired. But these advantages are more than outweighed by the poor performance of the mirror when used for solar work. Not only is a large amount of diffuse light sent into the spectroscope, but the distortion of the mirror by the sun's heat soon changes a prominence into a shapeless mass when the diffuse light does not render it entirely invisible. An example of the extreme sensitiveness of the mirror to slight heating was recently given me by Mr. Clark. He said that, when it was first set up for night work, the heat radiated from the brick pier upon the back of the mirror so distorted it that no star image could be obtained. This was due to the unequal radiating power of the different surfaces of the mirror, and the difficulty was at length partially overcome by covering the circumference and sides with bright sheet tin, and thus rendering their radiating power more nearly that of the silvered front surface. But it is obvious that the direct solar rays could not but have a far greater effect than the feeble radiation from the pier, and the result was that prominences could only rarely be seen at all, and even when seen they were so faint and badly defined as to be practically useless for photographic work. As I have already remarked, none of the equatorials of the Observatory were available for this work; so the best that could be done was to use the horizontal telescope on such days as anything at all could be seen with it.

Attempts were made to photograph through the F and H$\gamma$ lines with ordinary dry plates, through $D_3$ with plates dyed with erythrosine, and through C with plates dyed with cyanine and alizarine blue. In the first three cases, Method A was used with some degree of success. F and H$\gamma$ gave the general outlines of the prominences rising above the limb, and on one plate taken through F two prominences are shown. The line $D_3$ was photographed by the use of a tangential slit, the sun's image being maintained stationary by the slow motions. At the red end of the spectrum, the cyanine and alizarine plates were found to be hardly sensitive enough for the purpose. It is hoped that further experiments with these and other dyes will remove the difficulty.

The investigation is soon to be resumed, under much better auspices, at the Kenwood Physical Observatory. The large spectroscope already described will be attached to a long-focus twelve-inch equatorial refractor, built especially for spectroscopic work. The object glass of this instrument is by Brashear, and the mounting by Warner and Swasey. It is covered by a dome 26½ feet in diameter, giving ample room for any desired apparatus at the eye end. A new frictionless arrangement has been devised, which by a simple change gives either a stationary slit and moving plate, or a moving slit and stationary plate. It is also considered possible, that under certain circumstances two or more slits may be used before the plate, thus giving simultaneous photographs of the same prominence several lines at once, and allowing accurate comparisons of form to be made. Professor Young has suggested that the motion of the plate in Method A may be so changed as to correct the distortion of the prominence in the plane of dispersion. I mean also to try a rotating cylinder at the focus of the spectroscope, carrying on its circumference a strip of celluloid photographic film close behind the stationary slit. This will probably give the greatest steadiness of motion obtainable, if used with a carefully made clepsydra, possibly of the form perfected by Dr. Draper.

The sun-spot minimum being now well past, it is hoped that prominences will be more frequent and more brilliant than was the case last winter, and the substitution of an equatorial for the horizontal telescope will certainly render the solution of the problem much less difficult.

KENWOOD PHYSICAL OBSERVATORY, CHICAGO,
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